Available online at www.sciencedirect.com

ScienceDirect

International Journal of Pavement Research and Technology 10 (2017) 139–147

www.elsevier.com/locate/IJPRT

Non-destructive evaluation of sustainable pavement technologies using artificial neural networks

Fabricio Leiva-Villacorta [a,*], Adriana Vargas-Nordcbeck [a], David H. Timm [b]

[a] National Center for Asphalt Technology – Auburn University, 277 Technology Parkway, Auburn, AL 36830, United States
[b] Auburn University, Department of Civil Engineering, 201 Harbert Engineering Center, Auburn, AL 36849, United States

Received 5 October 2016; received in revised form 16 November 2016; accepted 20 November 2016
Available online 1 December 2016

Abstract

Evaluation and characterization of pavements that incorporate sustainable technologies and materials such as warm mix asphalt (WMA) and Reclaimed Asphalt Pavements (RAP) becomes especially important for their future applicability. Artificial neural networks (ANN) have been recently used to forward-calculate pavement layer moduli from falling weight deflectometer (FWD) test results. A full bond layer interface condition is commonly assumed to perform pavement layer moduli calculations; however, this condition is not guaranteed to happen in the field. The objective of this study was to develop ANN models capable of predicting pavement layer moduli rapidly and reliably for full bond and full slip layer interface conditions. ANN models were used to estimate the moduli of the National Center for Asphalt Technology (NCAT) Test Track structural sustainable sections for the full bond (FB) condition and the full slip (FS) condition. The results indicated that WMA sections had lower moduli at all tested temperatures compared to a control section (7–10% lower), likely due to the reduced binder aging experienced by these sections. RAP sections had higher moduli (16–43% higher) and were less susceptible to changes in temperature due to the presence of stiffer aged binder. Overall, backcalculated layer moduli using the conventional iterative approach had the highest error, followed by a significant decrease in error by ANN predicted moduli under full bond condition. However, the consideration of the ANN with full slip condition yielded the best results (lowest error).

Keywords: Warm mix asphalt; Reclaimed Asphalt Pavements; Neural networks; FWD; Pavement evaluation

1. Introduction

The asphalt industry has been developing sustainable paving technologies and practicing green-build techniques since the 1960s through the reduction in emissions from asphalt plants and through recycling [1]. Since 1970, with the implementation of the Clean Air Act, total emissions from asphalt plants have dropped by more than 97% while annual production has increased by more than 250% [2].

The asphalt industry has been implementing the use of warm mix asphalt (WMA) as means of reducing greenhouse gas emissions. On the other hand, asphalt pavement is the most recycled material in the nation, with about 100 million tons of asphalt pavement being reclaimed every year and approximately 80% of it being recycled back into new asphalt mixes [3]. Evaluation and characterization of pavements that incorporate sustainable technologies and materials such as WMA and Reclaimed Asphalt Pavements (RAP) becomes especially important for their future applicability.

One of the most common field tests used to obtain pavement layer moduli is the falling weight deflectometer (FWD). This apparatus drops a circular load on the pave-

* Corresponding author.
E-mail address: leivafa@auburn.edu (F. Leiva-Villacorta).
Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2016.11.006
1996-6814/

ment structure that is representative of a heavy vehicle tire load. With the use of deflection sensors, the resulting deflection basin of the pavement surface can be measured. Backcalculation is an inverse process that utilizes deflections, thicknesses and load levels as the input variables to solve for layer properties. The computational procedure to solve this problem includes both a pavement response model and an optimization algorithm. Basically, it is an iterative process that compares calculated deflections with the measured deflections. If the difference between the calculated and measured deflections is acceptable, then the assumed layer moduli become the actual moduli. The problem with the backcalculation process is the non-uniqueness of the results and a good match between the deflections does not guarantee that the backcalculated moduli are reasonable for a given cross-section. On the positive side, measured strains have been compared to backcalculated (theoretical) strains based on layered elastic analyses with satisfactory results (±5 percent difference) [4].

Artificial neural networks (ANN) have also been used to calculate pavement layer moduli and critical pavement responses from FWD test results [5,6]. An ANN is a massively parallel distributed processor that has a natural propensity for storing experimental knowledge and making it available for use [7]. Consequently, knowledge is acquired by the network through a learning (training) process. The aim of the learning process is to map a given relation between inputs and outputs of the network. Artificial neural networks (ANN) are a sort of mathematical tools, which instates a relation between a set of input numbers and output numbers. ANN method has been used extensively to solve complicated modeling problems in field of pavement engineering [8–14].

One of the most common networks selected by pavement researchers uses a back-propagation algorithm [5,8,15]. This learning algorithm is applied to multilayer feed-forward networks consisting of processing elements with continuous and differentiable activation functions. Such networks associated with the back-propagation learning algorithm are also called back-propagation networks [7]. Errors are calculated from outputs and targets and then used to update output weights by back propagating the error. The process continues until the performance of the network is optimized (i.e. minimum mean square error – MSE calculated between outputs and targets is obtained).

Even though, ANN models are excellent tools for pavement layer moduli estimation, these models depend on how the field conditions are being modeled. Romanoschi and Metcalf [16] evaluated the potential error in pavement layer moduli backcalculation due to improper modeling of the layer interface condition. It was found that the condition of the wearing-binder layer interface leads to an error in backcalculated moduli for the granular base layers, for both flexible and semirigid structures. Lenngren and Olsson [17] studied the effect of performing conventional backcalculation on a four-layer system with full slip (air gap) condition between layers. Their results indicated that the backcalculated modulus of the unbound base was most affected by adding friction between layers. The effect on the unbound base is considerable and may explain a lot of underestimated modulus on base courses.

This document focuses on the evaluation and characterization of pavements that incorporate sustainable technologies and materials such as WMA and RAP. The methodology incorporates advanced modeling through the use of ANN models and full slip interaction between layers.

1.1. Objective

The objective of this study was to develop ANN models capable of predicting pavement layer moduli rapidly and reliably for the sustainable pavement structures placed at the NCAT Test Track.

1.2. Scope

To accomplish the objective of this study, layered-elastic analysis (LEA) was used to generate synthetic databases. A three-layer structure with typical properties obtained from five sections built in 2009 at the National Center for Asphalt Technology (NCAT) Test Track was model to compute deflection basins. Two ANN models (full bond and full slip) were trained using the software MatLab. The layer moduli and thicknesses of the synthetic database were used to compute deflections under a full slip layer interface condition and then to perform conventional backcalculation which considers full bond conditions. This was performed to evaluate the potential errors in pavement layer moduli backcalculation due to improper modeling of the layer interface condition. Finally, ANN models were used to estimate the moduli of seven structural sections for the full bond condition and the full slip condition. The outcomes of both models were compared and analyzed to the draw final conclusions.

2. Development of ANNS for sustainable sections at the 2009 Test Track

2.1. Artificial feedforward neural networks

This type of ANN is also a massively parallel distributed processor that has a propensity for storing experimental knowledge and making it available for use. It means that knowledge is acquired by the network through a learning (training) process [7]. The strength of the interconnections between neurons is implemented by means of the synaptic weights used to store the knowledge. The learning process is a procedure of adapting the weights with a learning algorithm in order to capture the knowledge. In other words, the goal of the learning process is to map a given relation between inputs and outputs of the network.

Fig. 1 shows an example of feedforward ANNs. In this case, the neurons are grouped into layers. The input layer